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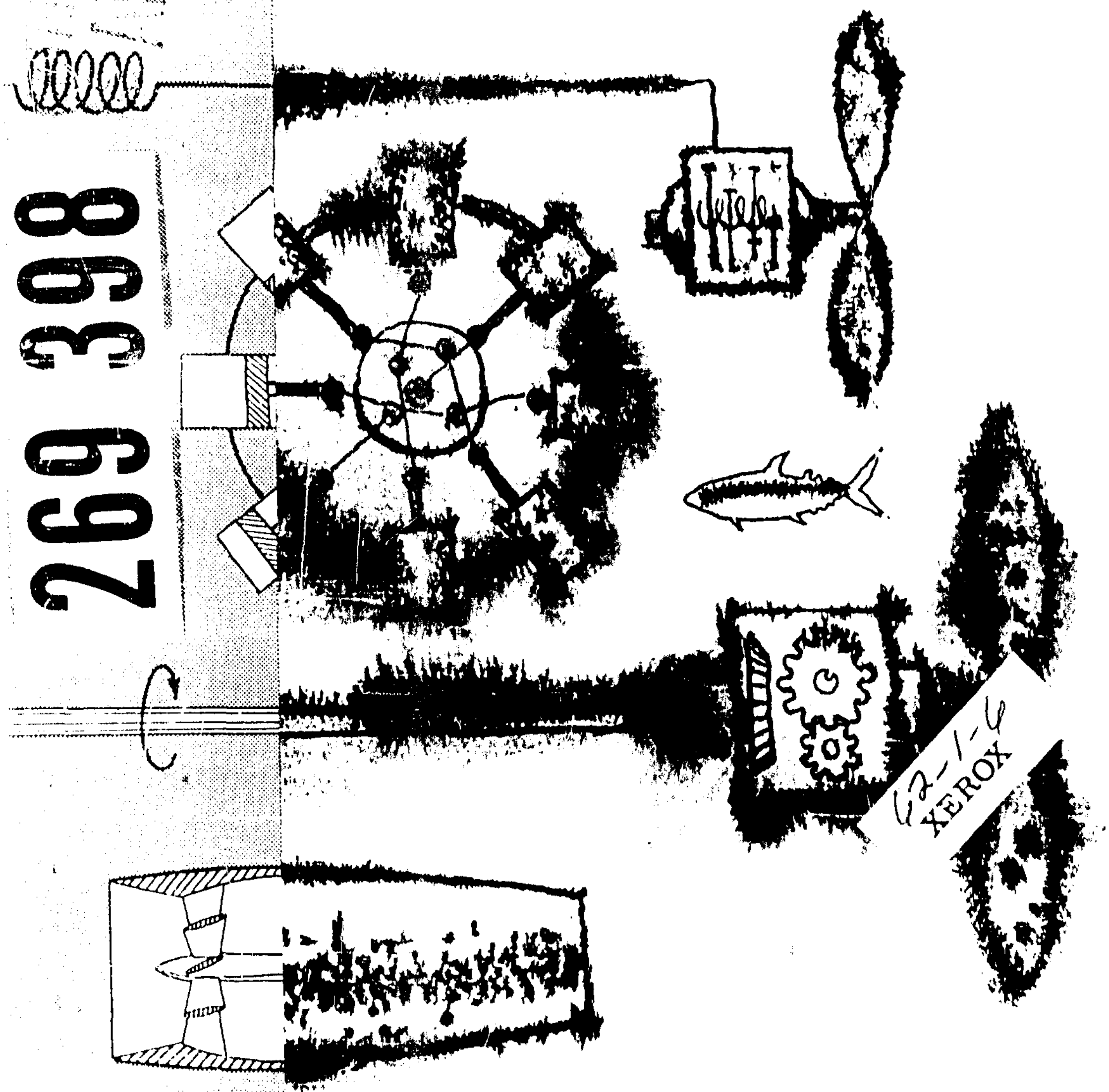
PPENDIX II

VALUATION OF SUBMARINE POWER TRANSMISSIONS

H. STERN

LOW MAINTENANCE MACHINERY FOR SUBMARINE POWER PLANTS



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PREPARED FOR OFFICE OF NAVAL RESEARCH, UNITED STATES NAVY
BY MEDIUM STEAM TURBINE, GENERATOR AND GEAR DEPARTMENT
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GENERAL ELECTRIC

Appendix 11

EVALUATION OF SUBMARINE POWER TRANSMISSIONS

By

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October 1961

This report contains a detailed discussion of one phase of the Low Maintenance Machinery Study program performed by the General Electric Company under Contract NONR 3485 (00) and was written at the conclusion of that phase. It is presented in support of the Final Report of December 1961. While the results of this study phase contribute to the findings of the Final Report, certain conclusions drawn in the Final Report have the benefit of additional information obtained or generated in the over-all program and subsequent to the writing of this Appendix. The conclusions presented herein are, therefore, subject to modification by the Final Report.

EVALUATION OF SUBMARINE POWER TRANSMISSIONS

This report is the summary of the evaluation of transmission systems for steam-powered submarines. Following a more detailed investigation of certain types of fluid transmissions, all information then available on mechanical, fluid, and electrical transmissions was collected. The resulting facts were arranged in a total of 31 different power train configurations. An evaluation of these combinations is shown in Table I. A graphical representation of Table I is presented in Figures 1, 2, and 3 giving a comparison of steam consumption, weight, and system complexity.

Inspection of the merits of each of these 31 transmissions and comparison with the systems design goals reduced the field to the four transmissions presented in Figures 4, 5, and 6. From a closer inspection of these figures, it can be concluded that the direct coupled steam turbine is the only presently feasible transmission system which meets the reliability, maintenance, and noise requirements prescribed in this program. The steam motor direct drive is superior to the steam turbine because of its considerable weight advantage, Its application will not come about, however, until the machinery has been developed. Third place in the lineup of feasible transmissions can go to either hydraulic or electric transmissions dependent mainly on the weight versus efficiency criteria imposed on the system. For this evaluation, we have chosen the electric transmission which promises to be more efficient than any means of power transfer other than a gear-driven propeller. The weight of this transmission, however, is far in excess of even the direct coupled steam turbine.

Tabulated Survey

A series of 31 combinations of prime movers, transmissions, and propellers was assumed. All available information is tabulated and used in the final comparison and selection of the most promising power plant. The following items are tabulated and the explanation as to assumptions made is presented below.

Prime Movers and Transmission Match

Variable or constant speed machines can be selected. The variable speed machines may be reversing or unidirectional. Depending on the nature of the prime mover fixed ratio, variable ratio, or reversing transmissions must be chosen or controllable and reversible pitch propellers used. Columns 1-3 reflect these combinations. For example, the choice of a C&RP propeller makes a reversing torque converter superfluous. Similarly, a reversing turbine is of no purpose with a Fottinger Transformer since this transmission cannot transmit reverse rotation.

Prime Movers

Generally, the constant speed turbines are desirable since vibration mounts can be designed to provide for quietest operation, bearings run at constant conditions, and ship service generators can be direct coupled to propulsion turbines. Unfortunately, the power consumption at low load is high in such machines, particularly when coupled to fluid transmissions. Since a large percentage of the power plant operation takes place at a small fraction of full load the economy of constant speed prime movers is very poor.

Steam Consumption (Figure 1)

This is the average hourly steam consumption for the duty cycle perscribed by ONR. Due to its security classification it is not reproduced here. The constant speed turbines were controlled by throttling. Reactor steam-pressure/demand characteristics are included in these considerations. In the bar graph the steam consumption for a 60-day mission is given (i.e. 60 x 24 x steam rate per hour). In column 4a it is assumed that all propulsive effort was taken from the main propulsion system. Column 4b shows the same power plants evaluated for the conditions where the lowest ship propulsion power level is provided from ship service generators.

Weight (Figure 2)

See attached Table II for unit weights used. Only power plant and transmission weight are considered. When the ship service load is generated with the same power plant as propulsion power the additional power requirements will raise total plant weight. This increment is to be assigned to ship service power. It is omitted from the figures shown here. A correction was made for the effects of transmission efficiency on prime mover weight, assuming fixed weight per HP. The output power at the propeller shaft was held constant at 15,000 HP.

Number of Components (Figure 3)

This column is intended to give a quantitative measure of the physical complexity of the power plant. Each major unit is classed on an equal weighting basis. Since system reliability is directly affected by the number of series elements in the chain, this number is an important factor in judging potential reliability. Where the power train splits into two equal branches each of which can be used to operate the ship, even if at reduced capacity, the parallel combination has been adjusted to reflect the improved reliability. (see Table III, column 1)

Number of fluid systems (Figure 3)

Since fluid systems of all types are a major factor in both maintenance and reliability each distinct fluid system has been accounted for in column 7. In the bar chart, Figure #1, these have been added to the major components on an equal weight basis. Control oil circuits, lube systems, make-up supplies, wherever these cannot be combined, have been added up. In the case of the acyclic DC generators both the inert atmosphere in the generators and motors and the liquid metal sliprings are counted a fluid system each. (see Table III, column 2)

Manufacturability

In the production of all the components varying degrees of skill, precision and design sophistication are needed. Materials of a wide range of availability and cost are needed. Column 8 lists an opinion of this quantity reduced to a 1-5 scale. Off-the-shelf items will be classed as 1 while precision built equipment needing strategic materials, and much manpower is classed as 5.

Critical Components

In columns 9 and 10 critical components are listed and the reason for their criticality stated in terms of this program. Thus while a gear reduction system may have excellent reliability, few fluid circuits, it has to be derated because of noise.

Low Maintenance

So far no mention has been made of low maintenance machinery in my reports. It must be assumed that certain functions will be performed by a system for a limited period of operation. Thus a periodic refuelling of the steam generating reactor is necessary. Certain limited life components must be replaced. In this category fall hydraulic or lube oil, fluids seals, and filters. A qualitative measure of low maintenance will then be found in the columns 4 since steam consumption will have a direct bearing on refuelling intervals. A second measure of maintenance is found in column 7 since each such system contributes to the frequency of maintenance.

TABLE I

COMPILATION OF TRANSMISSION

SYSTEM DATA

		1	2	3	4a	4b	5	6	7	8	9	10
		Prime Mover			Steam Consumption in #/hr	1000 of duty cycle						
No.	System	Speed	Rotation	Propeller			Weight 1000 #	Number of components	Least Number of Fluid systems	Manufacturability	Limiting Element	Reason
1	Turbine and Double Reduction	Var	Rever-	Fixed	23	14	215	5	2	2	Gear	Noise
2	Gear		sing		23	14	215	5	2	2	Gear	"
3	Direct Coupled Turbine				41	18	335	3	2	2		
4	Direct Coupled Turbine		Uni-Di-	C&RP	41	18	335	3	3	2	C&RP	Relia'ty
5	Turbine & 5:1 Torque Conv.		rection-	C&RP	29	15	311	4	3	2	T-C	Develop't
6	" " " "		al	Fixed	29	15	331	4	2	2	T-C	
7	Turbine & 30:1 " "				65	24	235	4	2	3	T-C	
8	Turbine & Split Hydrodyn. Trans.				65	24	250	4	2	2	trans	
9	Turbine & Split Hydraulic Trans.				65	24	250	4	2	4	Motor	
10	" " " "				65	24	310	4	2	3	Motor	
11	Turbine & Tandem 5:1 T-C's				35	17	240	5	3	2	HS.T-C	
12	" " " "	Const			172	46	240	6	3	2	HS.T-C	
13	Turbine & Split Hydraulic Trans.				170	46	310	5	2	3	trans	
14	" " " "				170	46	250	5	3	4	Motor	
15	Turbine & Split Hydrodyn Trans.				170	46	238	5	3	2	trans	
16	Turbine & 5:1 Torque Conv.				174	48	358	5	3	2	T-C	
17	" " " "			C&RP	114	36	338	5	3	2	T-C	
18	Direct Coupled Turbine				107	35	335	3	2	3	C&RP	Relia'ty
19	Turbine, Gear & 5:1 T-C				116	48	233	5	4	2	Gear	Noise
20a	Turbine & Double Red. Gear				98	29	215	5	3	2	Gear	Noise
20b	Turbine, T-C, & Gear				153	48	229	5	4	2	Gear	Noise
21	Turbine & Fluid Disk Drive			Fixed	240	62	?	4	2	5	trans	Develop't
22	Turbine and DC (Acyclic) Trans.				104	34	375	4	3	3	trans	NaK
23	Turbine and DC Gen/Motor Drive				~120	~38	>400	3	2	2	trans	size
24	Turbine and Fluid Roller Drive				240	62	?	4	2	4	trans	Develop't
25	Steam Motor Direct Drive			C&RP	60	27	143	3	2	2	C&RP	Relia'ty
26	" " & 5:1 Torque Conv.	Var		C&RP	75	32	185	4	3	2	"	"
27	" " & 5:1 V-Belt Drive		Rever-	Fixed	~42	~21	?	4	3	3	V-Belts	size
28	" " Direct Drive		sing		36	23	143	2	2	2	SteamM.	Develop't
29	Turbine & DC (Acyclic) Drive		Undirec.		23	14	375	3	4	3	trans	NaK
30	Steam Motor (Water Lube)		Reversing		50	27	153	2	2	5	SteamM.	Bearing

4a. Main propulsion unit perfor[illegible] at all power level

4b. Propulsion power below 1% max. power is taken from ship service generators.

TABLE II

Assumed Power Plant Weights for 15,000 HP shaft output of each component

Steam turbines & condenser	10,000 rpm	135,000 lbs.
	3,600 rpm	165,000 "
	1,000 rpm	235,000 "
	300 rpm	335,000 "
Steam motor & condenser	300 rpm	143,000 "
	1,000 rpm	115,000 "
Gearing	double reduction	80,000 "
"	low speed single reduction	70,000 "
"	high speed single reduction	20,000 "
Torque Converter	low speed (5:1)	60,000 "
	high speed (5:1)	10,000 "
	wide range	65,000 "
Reversing T-C	additional weight	20,000 "
Split Hydraulic Transmission		40,000 "
D.C. Acyclic	3600 - 300 rpm	210,000 "
Hydrodynamic	Transmission split	80,000 "

TABLE III

Number of Components and Fluid Systems

	Comp'ts	Fluid Systems
Turbine variable speed undirectional	1	1 or 2
reversing	2	1 or 2
constant speed	1	1 or 2
Reduction gear, each mesh	1	1 per set
Torque converter, each step	1	1 for set
reversing unit	1	same
C&RP propeller inclusing controls	2	1
Fixed propeller	1	0
Split transmission, each series element	1	1 for set
Electric Drive each series element	1	2 for set
Split transmissions: pair of 2 drive motors and 2 propellers	1	1 for set
Steam motor	1	1 or 2
Controls other than turbine speed controls (i.e. torque-converter pitch control)	1	1

FIGURE 1

COMPARISON OF SYSTEM STEAM CONSUMPTION FOR 60-DAY MISSION

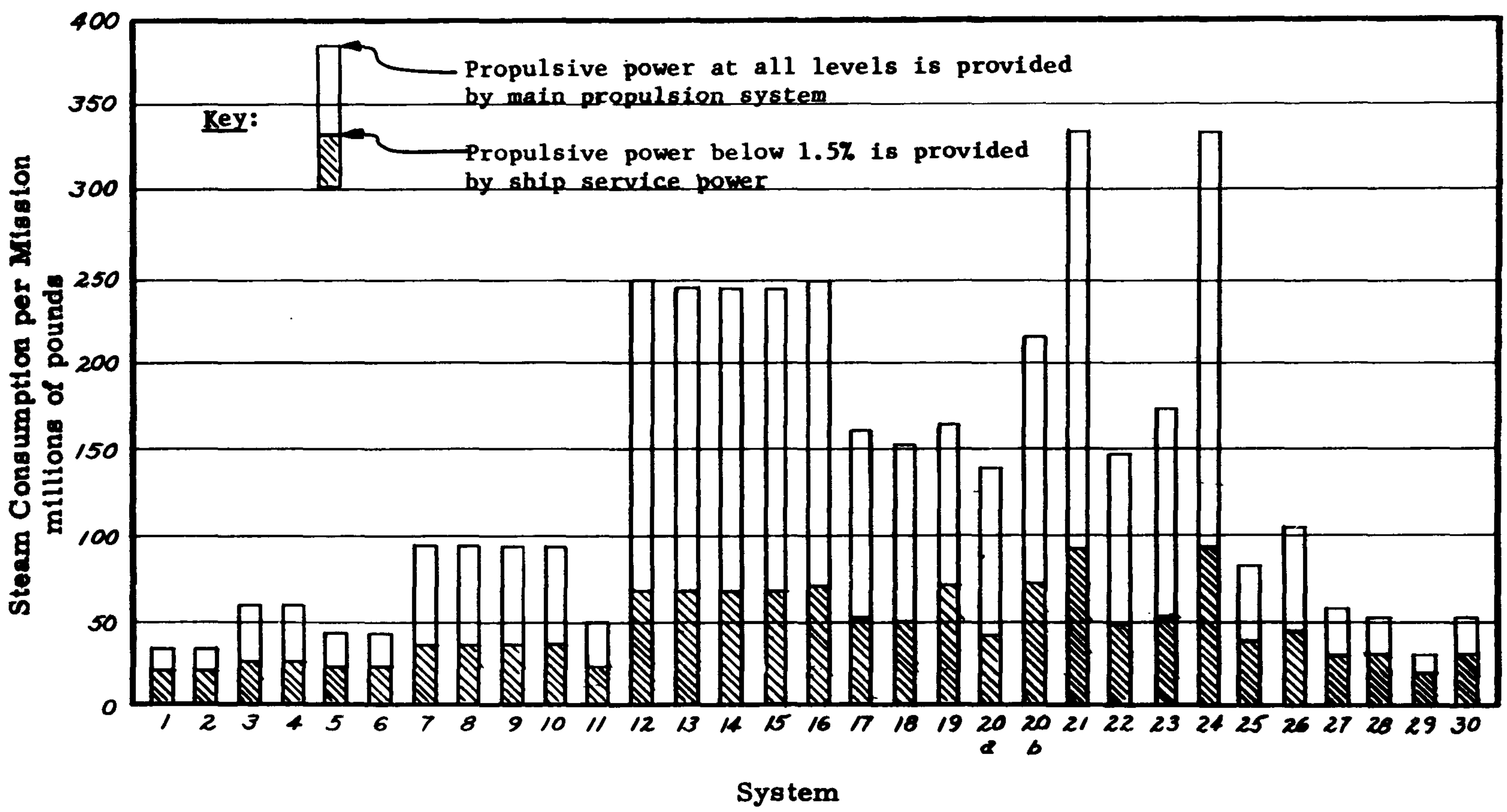


FIGURE 2

COMPARISON OF SYSTEM WEIGHTS

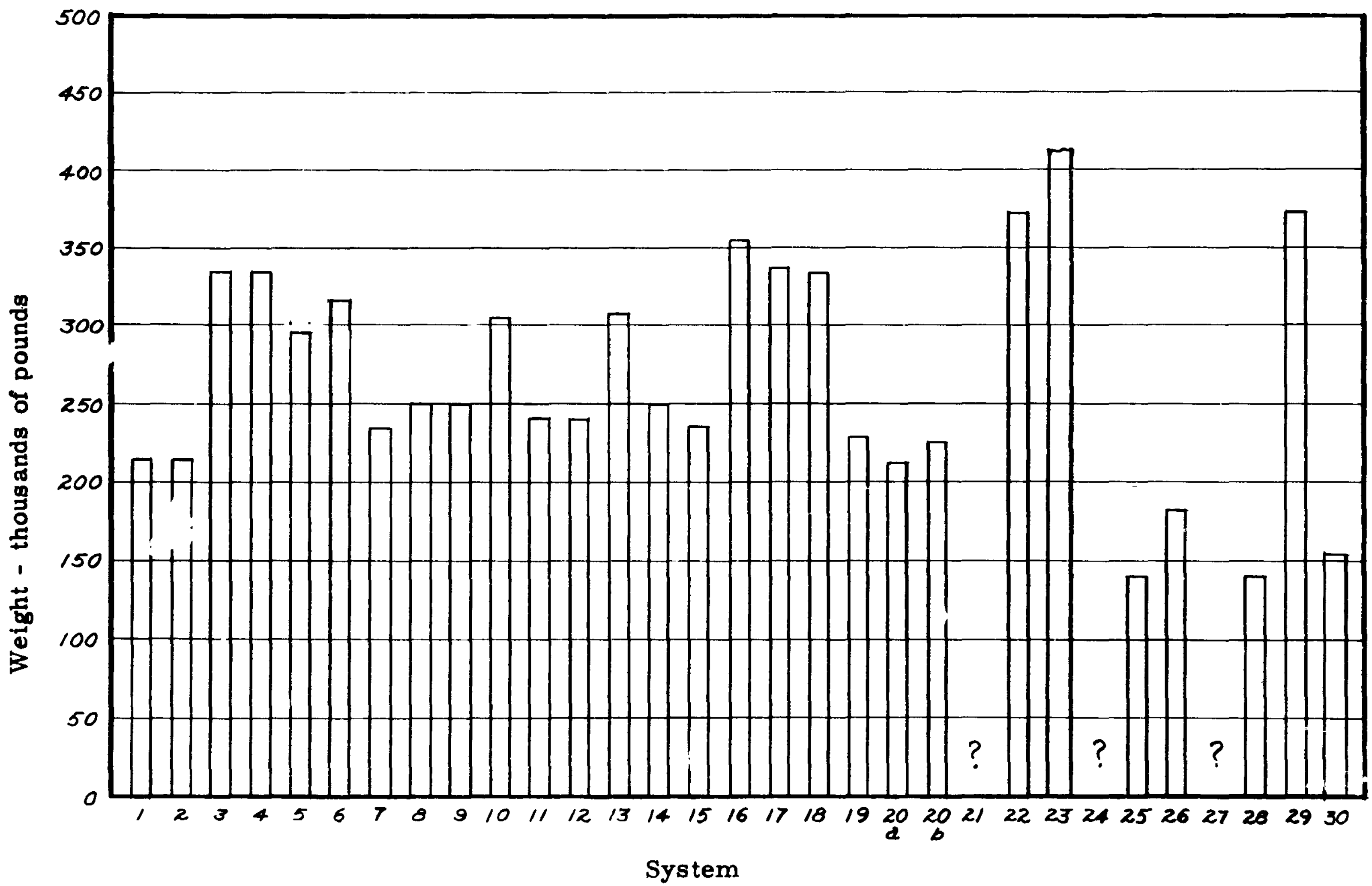


FIGURE 3

COMPARISON OF SYSTEM COMPLEXITY

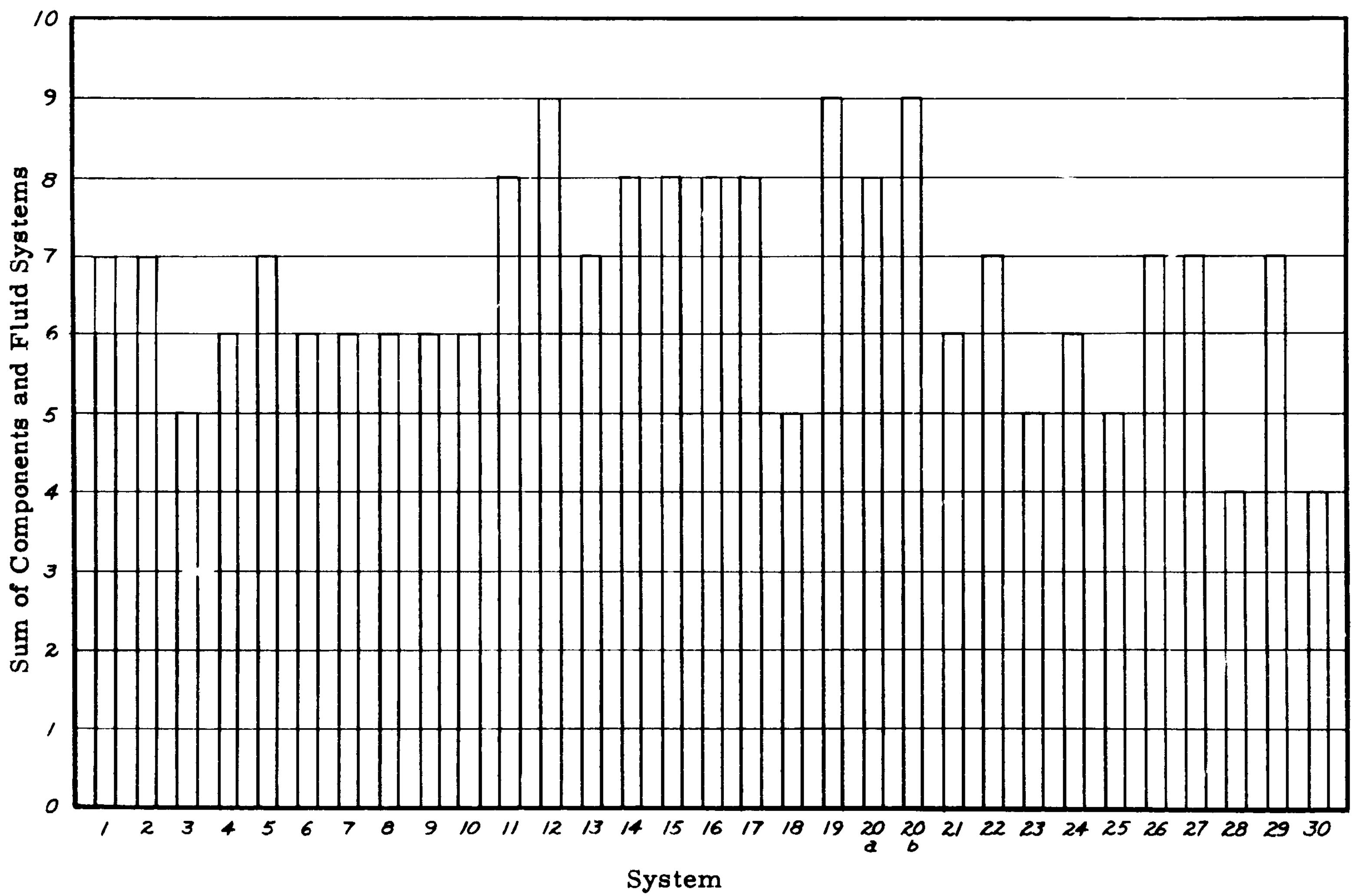
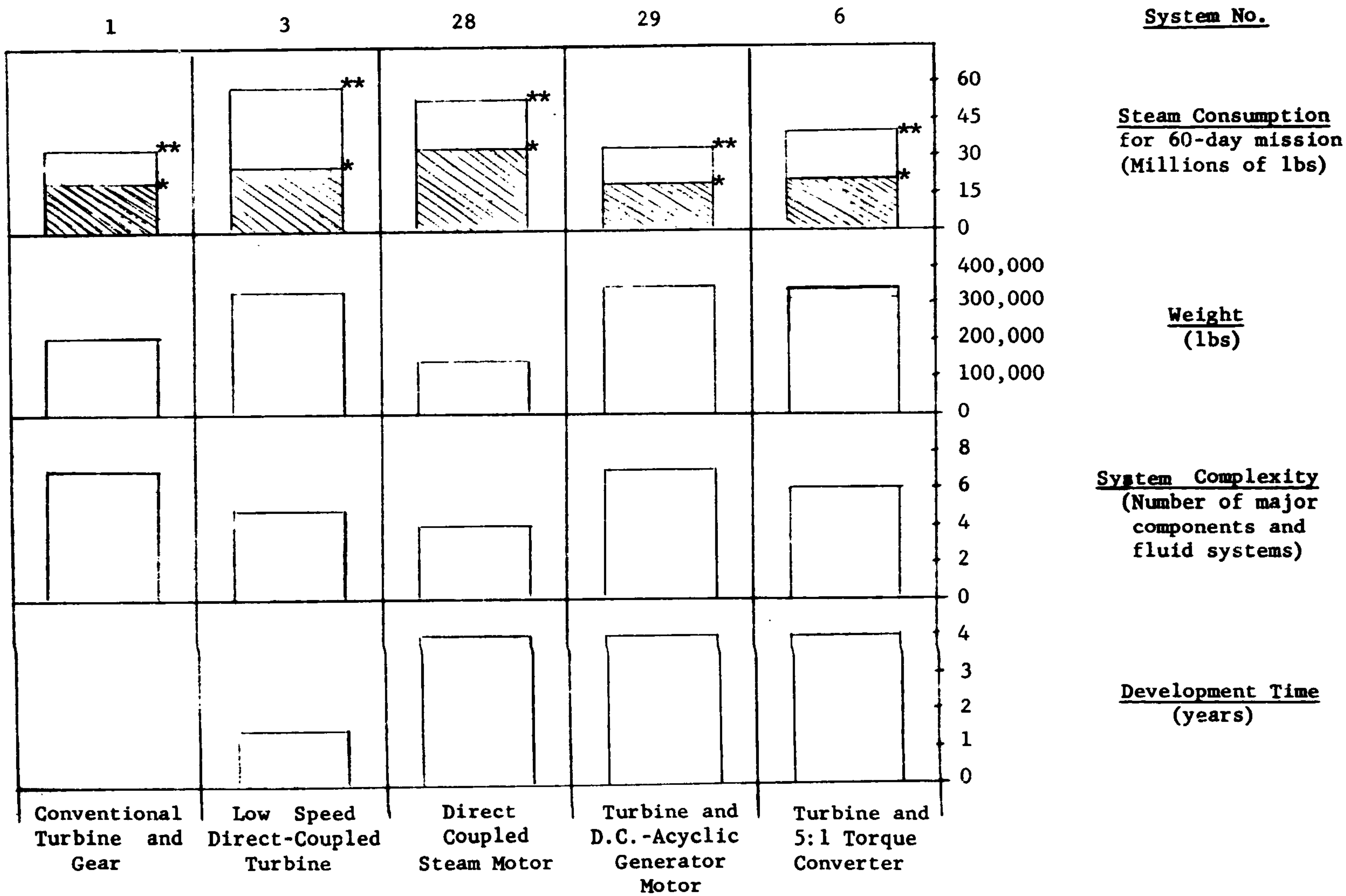


FIGURE 4

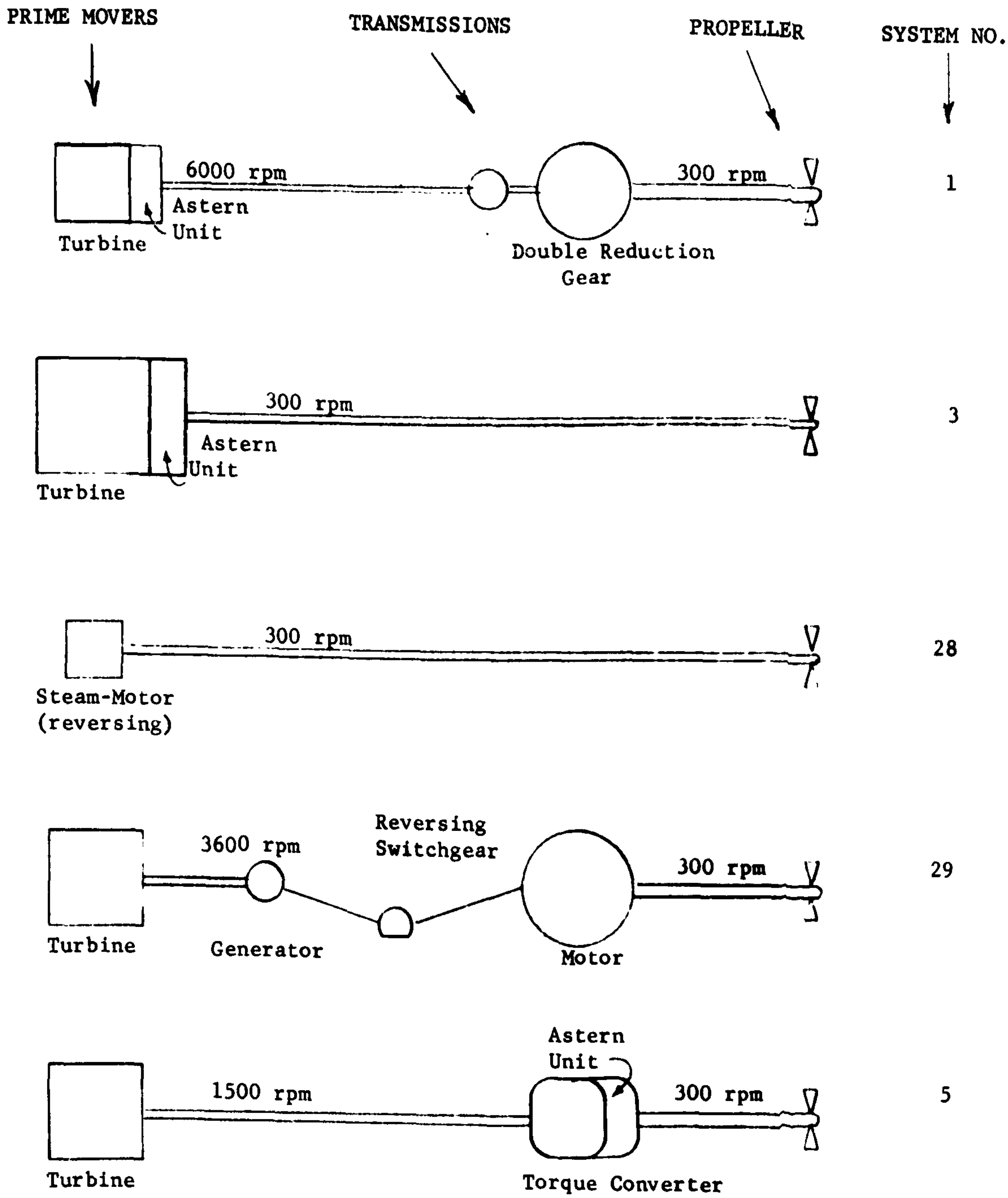
COMPARISON OF FOUR POWER PLANTS WITH STATE-OF-ART PLANT



*Propulsive power below 1.5% is provided by ship service power.
**Propulsive power at all levels is provided by main propulsion system

FIGURE 5

SYSTEM SCHEMATICS



H. Stein
10/18/61